Mass and Angular Momentum of Sgr A*

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Over the past four years it has become increasingly clear that Sgr A* is not a steady source but is more or less continuously flaring. The first large flare was observed in X-rays on October 26, 2000 with *Chandra* [1]. A second, even brighter X-ray flare went off on October 3, 2002 and was recorded by *XMM-Newton* [2]. In the near infrared (NIR) two bright flares were observed on June 15 and 16, 2003 with the VLT *NACO* [3]. The two NIR flares showed quasi-periodic oscillations with a period of 16.8±2 min which if interpreted as the Kepler period of the last, marginally stable orbit implies a spin of the Sgr A* black hole (BH) of $a = 0.52$ adopting a BH mass of $3.6\times10^6 \mathrm{M}_\odot$ [3]. The two X-ray flares did not only show a quasi-period consistent with the NIR period but indicated additional quasi-periods, which fall into four groups [4] (c.f. Fig. 1). In a first attempt we associated these quasi-periods with the three fundamental oscillation modes a particle can have when orbiting a rotating BH representative for an accretion disk [4]. These are the Kepler frequency Ω_K (azimuthal), the radial epicyclic frequency Ω_R (radial) and the vertical epicyclic frequency Ω_V (polar). For the first three quasi-periods a consistent solution was found for $\mathrm{M_{BH}} = 2.72^{+0.12}_{-0.19}\times10^6\ \mathrm{M}_\odot$ and $a = 0.9939^{+0.0026}_{-0.0074}$. However, it had to be assumed that the oscillations originate from two different orbit radii, and for the fourth period no satisfactory explanation was found [4].

A closer look reveals that the average frequencies of the first three groups are consistent with a frequency ratio of 1:2:3 (c.f. Fig. 1). Similar to what Abramowicz & Kluźniak [6] have proposed to explain the 3:2 frequency ratio observed in microquasars I suggest that the 3:1 frequency ratio is due to a resonance between Ω_V and Ω_R at some orbital radius r_{31}. The frequency in between is either the beat frequency of Ω_V and Ω_R or the first harmonic of Ω_R. This assumption results in a relation between r_{31} and a. The additional requirement of the existence of a 3:2 resonance of Ω_V and Ω_R at a radius r_{32} and the same a such that r_{31} and r_{32} are commensurable orbits, i.e. $\Omega_\mathrm{V}(\mathrm{r}_{31}) = 3\times\Omega_\mathrm{R}(\mathrm{r}_{32})$, produces a single solution for $\mathrm{r}_{31} = 1.546$, $\mathrm{r}_{32} = 3.919$ and $a = 0.99616$ [5]. r is measured in units of the gravitational radius. Interestingly, the same values of r_{31} and a can be derived in a totally different way. The inspection of the Boyer-Lindquist functions show that the orbital velocity $\mathrm{v}^{(\Phi)}$ described in the ZAMO-frame is no longer a monotonic function of r for $a > 0.9953$. In a small range of r $\partial\mathrm{v}^{(\Phi)}/\partial\mathrm{r} > 0$. This is a new effect of General Relativity which has been overlooked so far. For $2\pi\frac{\partial\mathrm{v}^{(\Phi)}}{\partial\mathrm{r}} = \Omega_\mathrm{R}$ and $\Omega_\mathrm{V} = 3\times\Omega_\mathrm{R}$ the same values for r_{31} and a are obtained as above. With r_{31} and a fixed $\mathrm{M_{BH}}$ is given by just the observed frequencies, so that $\mathrm{M_{BH}}/\mathrm{M}_\odot = 4603/\nu_\mathrm{up}$, with ν_up the highest frequency of the triplet in Hz. For Sgr A* $\mathrm{M_{BH}} = (3.28\pm0.13)\times10^6\ \mathrm{M}_\odot$ and $a = 0.99616$ [5]. This

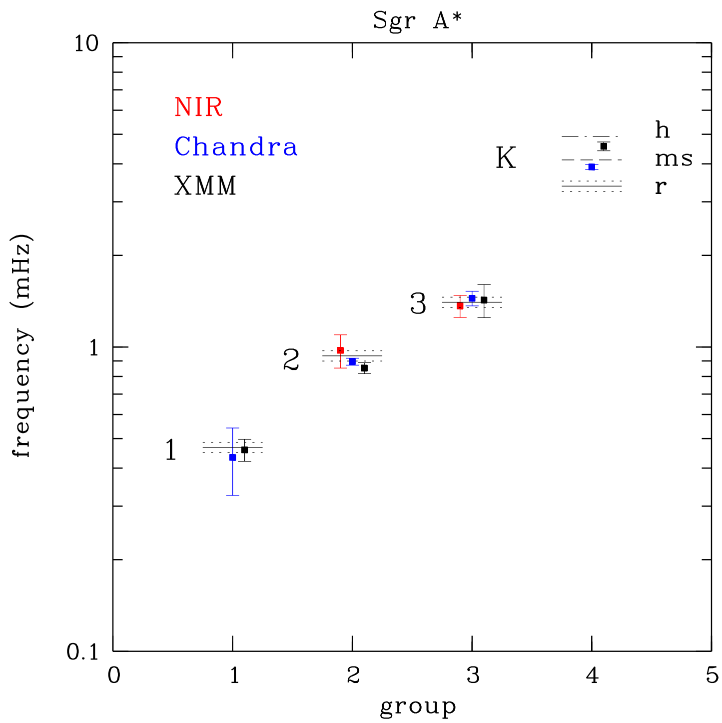

Fig. 1. The four groups of frequencies found in the NIR and X-ray flares of Sgr A*. The solid horizontal lines indicate the best fit to the measured frequencies of groups 1, 2 and 3 for a frequency ratio of 1:2:3; the associated dashed lines correspond to $\pm\ 1\sigma$ errors. The best fit Kepler frequencies (K) for the resonance orbit (r_{31}), the marginally stable orbit (ms) and at the event horizon (h) are compared with the two high frequency measurements [4, 5]. Apparently Kepler frequencies for radii below the marginally stable orbit exist, at least over the duration of a flare

value of M_{BH} may be compared with the dynamically determined masses of $M_{BH} = (3.59 \pm 0.59) \times 10^6\ M_\odot$ [7], $(4.07 \pm 0.62) \times 10^6\ M_\odot$ [8] and $(3.6 \pm 0.4) \times 10^6\ M_\odot$ [9]. The latter two measurements are for a distance of 8 kpc to Sgr A*.

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